Overview of FACTS Devices for Wind Power Plants Directly Connected to the Transmission Network

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Abstract - **Growing number of wind turbines is changing electricity generation profile all over the world. This brings challenges for power system operation, which was designed and developed around conventional power plants with directly coupled synchronous generators. In result, safety and stability of the electrical network with high wind energy penetration might be compromised. For this reason transmission system operators (TSO) impose more stringent connection requirements on the wind power plant (WPP) owners. On the other hand flexible AC transmission systems (FACTS) devices offer enhancement of grid stability and can facilitate grid code compliance for WPP.**

In this paper state-of-the-art in FACTS for WPPs with AC connection is given. FACTS devices with their properties are described. HVDC, which in literature is also often recognized as FACTS device, is out of this paper scope. Academic and industrial research in FACTS applicability for WPPs is summarized. Examples of few existing FACTS applications for wind farms are given.

I. Introduction

GROWING concern for limited fossil fuels reserves and CO-2 emission reduction stimulated development of the renewable energy sector. Especially, wind energy sector experienced huge thrust in recent years. As an example, in EU in 2008 one third of the total 23.85GW newly installed power capacity were wind turbine generators (WTG) [1]. There was more installed capacity in wind power than in any other generation technology. Moreover, 8.48GW of installed wind power capacity represented two thirds of the total newly installed renewable energy capacity in 2008 in EU. EWEA forecasts that by year 2030 total installed wind power capacity in EU will be in order of 300GW. In terms of share of energy market, it means that in 2030 wind energy would cover from 20.8% to 28.2% of European electricity demand (depending on the scenario) [2].

Integration of wind energy into power systems on such a large scale is not straightforward. Power system and its operation, was designed and developed around conventional power plants (CPP) with synchronous generators directly coupled to the grid. Wind power plants (WPP) have different characteristics from the conventional ones. Thus, because amount of wind power has become significant, grid performance and stability is affected [3]-[5]. Therefore, transmission system operators (TSO) were forced to impose new requirements for the connection of WTGs to the power network. This way, TSOs try to ensure that all regulatory actions, which are needed for maintaining grid stability, are still performed on a satisfactory level, when renewable energy is introduced into the picture.

On the other hand there exist instruments like Flexible AC Transmission Systems (FACTS), which were developed in order to dynamically control and enhance power system performance. Stability is the key aspect for introducing FACTS devices. Therefore, is seems quite natural, that one of the today's research topics is employment of FACTS devices for enhancing wind farm performance with respect to the grid codes and power system stability.

II. Grid Codes and WPP Limitations

TSOs requirements for all generation units are specified in formal documents called grid codes. However, non-conventional generation units are usually exempt from some of the general requirements and there is often additional set of rules that apply only to wind power (UK, Germany). Beside ability to deliver contracted amount of power, generating unit is required to assist in maintaining power system transient and steady state stability, participate in voltage and frequency control, assist in post fault recovery and also have capability to survive through the system faults [6]-[8]. Therefore, grid codes specify active and reactive power profiles, that generating unit must perform under different grid conditions.
In order to do so, first of all power plant must be able to continue its operation under off-nominal conditions. TSOs specify steady state voltage-frequency-time range in which generating unit must be able to operate without premature tripping. Around the nominal grid voltage and frequency continuous operation is required. For bigger conditions deviations power plant operation must be continued, but only for a limited time [6],[7]. Separate requirements are given for transients often referred as fault ride-through (FRT) requirements. TSOs specify time-voltage profiles, that show, when power plant is allowed to disconnect after fault occurrence [6],[7].

Active power control is required for maintaining the grid frequency. In most of the countries, WPPs are allowed to work at their maximum power point. Therefore they are exempt from primary and high frequency control requirement [7]. Normally, only active power down-regulation is required in case of over frequencies. Some TSOs specify minimum ramp-down and maximum ramp-up rates for active power [10],[11]. However, in the future higher requirements regarding WPPs contribution to active power and frequency

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regulation are expected. Draft of the new Spanish grid code for the wind power already mentions inertia emulation and power oscillation damping [12].

Voltage control and reactive power capability became a standard requirement for the Wind Power Plants. Grid codes specify minimal amount of reactive power (both lagging and leading) that in steady state WPP must be able to supply together with nominal active power [6],[7]. Special requirements are given for the disturbances, where the reactive current injection is prioritized over the active current, to support voltage stability. TSOs specify reactive current control characteristic that must be followed during transients [6],[7]. So far grid codes were specifying FRT characteristics based on symmetrical faults, since those would result in the highest voltage dips. However, in the future separate low-voltage profiles would be given for unsymmetrical faults and negative sequence current injection might be demanded [12].

WTGs can comply with the grid codes in various degrees, depending on the technology. Capabilities of the oldest, fixed speed technology are highly limited [14]. Therefore fixed speed wind turbines on their own can be regarded as grid code incompliant.

Much better performance can be expected from two variable speed wind turbine (VSWT) technologies: doubly-fed induction generator (DFIG) based, and full-scale converter (FSC) based turbines.

Because VSWT are fully or partially decoupled from the grid by frequency converters, they can quite easily tolerate small frequency and voltage deviations. Thus, voltage-frequency-time operation range can be met with proper converter control [21].

VSWT can comply with today's active power regulation requirement. Active power can be quickly limited by the converter control and with slower rate by pitch angle control [14]. VSWTs could even perform inertia emulation and participate in primary frequency control, if they would operate at de-loaded power curve (below maximum power point) [16]-[18]. However such solution is not cost efficient.

Steady state reactive power capability is very good in case of FSC-WTs, but limited in case of DFIG-WTs. According to [16] reactive power capability of DFIG based wind farm might be not enough in case of in case of the weak grids and some external support might be needed. For FSC-WTs reactive power capability is only matter of proper sizing of grid side converter (GSC), that it would be capable of carrying extra current [19]. However, it must be remembered that due to cables and transformer impedances Q capability at point of common coupling (PCC) of the whole WPP in not a simple multiplication of Q capabilities of single WTGs [20].

Transient behavior requirement is challenging for DFIG technology. Fault occurrence excites high rotor currents and causes overvoltage in the DC-link [58],[59]. To protect machine side converter (MSC) active crowbar protection will be triggered and chopper resistors would be activated to limit DC-link overvoltage. Due to over current protection, DFIG for some time loses its controllability [16]. Then it behaves like an ordinary induction generator [16]. On the other hand, GSC can provide some reactive power support [58],[59]. However, its capabilities might be too limited for grid code compliance [16],[58]. Moreover, due to active power imbalance turbine WT is prone to over speeding. To prevent tripping, pitch angle controller might need to be activated [16]. Again, FSC-WTs show better FRT performance. They can survive through the faults up to several seconds even with 0 volts at WT terminals [21]. Over speeding problem is solved by employing braking resistor in the DC-link. FSC-WTs can provide 1.0 p.u. reactive current during transients, as it is required by some of the grid codes [20].

III. Overview of FACTS devices

Flexible AC Transmission Systems are represented by a group of power electronic devices. This technology was developed to perform the same functions as traditional power system controllers such as transformer tap changers, phase shifting transformers, passive reactive compensators, synchronous condensers, etc. [38]. Particularly FACTS devices allow controlling all parameters that determine active and reactive power transmission: nodal voltages magnitudes and angles and line reactance [42]. Replacement of the mechanical switches by semiconductor switches allowed much faster response times without the need for limiting number of control actions [38]. However, FACTS technology is much more expensive from the mechanical one [39].

FACTS devices can be divided into two generations. Older generation bases on the thyristor valve, where newer uses Voltage Source Converters (VSC). In both categories there are corresponding devices performing similar services. Generally speaking, VSC technology offers faster control over a wider range [40]. Moreover, new generation does not need bulky reactors, thus size of these devices is considerably smaller than the thyristor controlled ones. However, VSC technology requires use of self commutating semiconductor devices which are more expensive, have higher losses and smaller voltage ratings when compared to the thyristors [41].

Another way of categorizing FACTS devices is by the way they are connected to power systems: shunt, series or shunt-series connection [41]. Main purpose of shunt devices is to provide reactive power compensation and dynamic voltage support of the lines or loads [40]. One of the shunt devices is the thyristor based Static VAR Compensator (SVC), which can be seen as a variable susceptance with a smooth control over a wide range from capacitive to inductive [43]. It is the oldest FACTS device and has the biggest number of applications [40]. VSC based Static Compensator (STATCOM) is another shunt connected device, which behaves like a synchronous voltage source which can inject or absorb reactive power [44]. Biggest advantage of STATCOM over SVC is the ability to maintain the reactive current output at its nominal value over a wide range of node voltages, where SVC has limited current capability when voltage is reduced. In conclusion SVC provides less support when it is mostly needed [15]. Thyristor controlled braking resistor, known as Dynamic Braking Resistor (DBR), is also a shunt FACTS device, however its purpose is different from SVC and STATCOM. DBR is mainly used for consuming generator available active power that cannot be sent to the grid due to voltage depression in the post-fault period. In such a way DBR improves rotor angle stability of CPPs.

Series devices have influence on the line effective impedance. Hence, they are basically used for controlling power flow and damping of power oscillations [40]. In this category of devices appears Thyristor Controlled Series Capacitor (TSCS), which can be regarded as adjustable reactance connected in series with the line reactance [40]. The same functions can be performed by a VSC based device, which is Static Synchronous Series Compensator (SSSC). It can be seen as series voltage source that compensates for the voltage drop on the line reactance [38]. However, SSSC offers better performance than TCSC, because its control characteristic is independent from the line current. Yet, due to the costs SSSC has not been applied yet on the transmission level. Another series FACTS device is Series Dynamic Breaking Resistor (SDBR). It offers similar functions as shunt DBR. But SDBR performance is better, since it is current not voltage dependent device [41].

It is worth pointing out, that STATCOM and SSSC topologies can be used to facilitate energy storage (ES) into the power system. It is feasible to install ES unit (super capacitor, battery, fuel cell, SMES, etc.) in parallel to the DC-link capacitors of these FACTS devices [56],[59]. Depending on the storage size, STATCOM and SSSC could perform additional functions like inertia emulation or frequency regulation. In fact SSSC configuration with small size energy storage, known as Dynamic Voltage Restorer (DVR), is used on the custom power level [40]. However DVR control principles are different than for regular SSSC.

Regarding shunt-series connection two devices should be mentioned Thyristor Controlled Phase Angle Regulator (TCPAR) and Unified Power Flow controller (UPFC). TCPAR works as a Phase Shifting Transformer (PST), where mechanical switches are replaced by solid state thyristor switches. Hence, TCPAR is also often referred as Static Phase Shifting Transformer (SPST) and it can be represented as a variable phase angle in series with line [43]. Its basic purpose is to control line power flow and damp power oscillations. One of the most advanced FACTS devices is UPFC, which can be treated as STATCOM and SSSC sharing the same DC-link. Such configuration gives three degrees of freedom (control variables), where all of the FACTS devices described so far have only one (except the ones with storage, which have two degrees of freedom) [41]. UPFC can regulate both active and reactive power flow through the series connection, and additionally shunt connected converter can control reactive power at the point of its connection. Therefore, UPFC can perform almost all of the functions of previously described devices. Except the functions that are related to the energy storage. This is because UPFC does not contain real power source, it only transfers power from one side to the other. Despite the very high costs there are already few UPFC applications [45],[46].

TABLE I
COMPARISON OF SERVICES PERFORMED BY DIFFERENT FACTS DEVICES

Service \ FACTS	SVC	STATCOM	STATCOM+ES	DBR	TSCS	SSSC	SSSC+ES	SDBR	TCPAR	UPFC
Reactive power generation/absorption	Good	Excellent	Excellent		Limited	Excellent	Excellent			Excellent
Active power generation/absorption			Excellent	Limited			Excellent	Limited		
Voltage control	Good	Excellent	Excellent		Limited	Limited	Limited		Limited	Excellent
Voltage stability improvement	Good	Excellent	Excellent		Good	Excellent	Excellent			Excellent
Power flow control	Limited	Limited	Limited		Good	Excellent	Excellent		Excellent	Excellent
Power oscillation damping	Limited	Good	Good	Limited	Good	Excellent	Excellent	Good	Excellent	Excellent
SSR mitigation					Good	Excellent	Excellent	Limited	Good	Excellent
Phase jump reduction				Limited				Good	Excellent	Excellent
Rotor angle stability improvement	Limited	Limited	Good	Limited	Good	Excellent	Excellent	Good	Excellent	Excellent
Flicker mitigation	Good	Excellent	Excellent							Excellent
Harmonics reduction		Good	Good			Good	Good			Excellent
Inertia emulation			Dependent				Dependent			
Curtailment			Dependent				Dependent			
Primary, secondary, tertiary reserve			Dependent				Dependent			
Frequency stability improvement			Dependent				Dependent			

Legend:

Performance	Excellent	Good	Limited	Dependent
Indicator	(red)	(orange)	(yellow)	(green)

There are even more advanced FACTS devices employing multiple VSCs, but they are out of this paper scope.

Table 1 summarizes services and performance level, that different FACTS devices offer for the power system.

IV. FACTS FOR WPPS – RESEARCH

Limitations of WPPs with respect to the grid codes were discussed in section II. The most modern WPPs equipped with the full scale converter turbines can meet all today's requirements, where FSWT based wind farms are to large extent not compliant. It will become common practice that newly built wind farms would need to prove their compliance through certificates [13]. If TSO demands are not covered, some countries, like Spain, require retrofitting or repowering of already existing wind farms [33].

Therefore, lot of research has been done toward improvement of wind turbines behavior. Especially, the ones of old type. Grid codes requirements are aiming in securing electrical grid reliable and stable performance. As was discussed in section III one of the key features of FACTS devices is enhancement of the grid stability. Hence, one of the research paths is application of FACTS devices for WPP support.

However, research in not only limited to the compliance with existing grid codes. FACTS devices might introduced new features for WPPs, which yet might be not demanded by TSOs, but would be beneficial in terms of grid stability. Below, main research areas regarding FACTS solutions are reviewed.

A. Voltage stability

Grid code requirement for steady state and transient reactive power support originates in voltage stability problem. Reactive power consumptions of the connecting lines and loads may lead to a voltage collapse in a weak heavily loaded system. Such situations are quite typical for wind generation, which is often placed in remote areas and connected with long lines.

If reactive power compensation provided by WPP is not sufficient, generated active power might need to be limited to avoid voltage instability [22]. It is especially likely for a wind farm employing FSWTs, which not only does not provide compensation but also consumes reactive power. Studies conducted in [22] show, that STATCOM applied at PCC of such plant greatly enhances system voltage stability, when connection to the main grid becomes weakened.

Similar case was studied for DFIG based wind farm in [25]. Due to crowbar protection, WPP reactive power support is limited. In result, without a STATCOM voltage cannot be restored when one of the connecting lines was disconnected due to fault. [26],[27] also analyze transient voltage stability enhancement of DFIG-WT based farms by a STATCOM. [27] clearly shows proportional relation between STATCOM ratings and level of support. In [26] influence of STATCOM control strategy on post-fault voltage evolution was studied. Optimized neural network controller allows faster voltage restoration with smaller overshoot and oscillations.

In [29] voltage stability of 486MW DFIG based offshore wind farm is indirectly addressed through the compliance analysis with UK grid codes. Conclusion is made that for short connection (20km), DFIG can comply with grid codes without additional support. On the other hand, for 100km cable, STATCOM of at least 60MVAr would be needed to provide adequate voltage support from the wind farm. However, authors suggest that in both cases it could be beneficial, to cover whole reactive power demand by STATCOM, without relying on WTGs capabilities. Control is faster and less complicated in case of one centralized device, when compared to tens of turbines, distributed over a certain area. In such a light, more studies are needed, because in most of the publications usually WPP is modeled as one aggregated WTG (e.g. [25]-[27]).

B. Frequency stability

Active power control requirement stated in the grid codes is related to frequency stability. To maintain frequency close to the nominal value, balance between generated and consumed power must be provided. When there is surplus of generated power, the synchronous generators (which are the core of the power system), tend to speed up. In result synchronous frequency rises. On the contrary, when there is not enough power generation to cover consumption, overloaded synchronous machines slow down and grid frequency drops.

There has been done lot of research on adding energy storage for wind turbines to improve active power control (e.g. [36],[37] discuss provision of frequency support, load leveling and spinning reserve). However, here particular interest is when energy storage is incorporated in FACTS device. Such studies have been done in [32], for STATCOM with Battery Energy Storage System connected in parallel to regular DC-link capacitors. According to simulation results, 5MWh storage helps 50MVA SCIG based wind farm to track ½ hour active power set point, which was based on wind prediction. Therefore need for balancing power is reduced and wind power can be better dispatched. It is clear that energy storage would bring benefits in terms of frequency control and inertia emulation. Still, primary STATCOM control functions are maintained.

C. Power oscillations

Grid codes do not specify requirements for power oscillation damping. However, this is one of the existing problems in power systems.

In [26],[35] it is shown that additional control loop for STATCOM controller can help to damp power oscillations, while basic voltage support function is maintained. In [26] optimized neural network controller attenuates local plant oscillations of DFIG based wind farm, during post fault period. In similar way, i.e. by means of STATCOM control, the same problem is addressed in [35]. Additional control loop is added to voltage controller, to emulate rotor friction and consequently provide damping torque. The damping loops are based on integrated time absolute error of rotor speed and active power. [35] states that with such arrangement output power oscillation are quickly damped after 3-phase fault.

The same controller allows to damp torsional oscillations of DIFG turbine drive train, modeled as two-mass system [35].

Wind farms have not been considered yet in literature, to play specific role in the intra-area or inter-area oscillations. On other hand FACTS devices are widely recognized as one of solutions for this problem, so such studies could be performed.

D. *Fault ride through*

As was discussed fault ride through is a technical challenge for wind turbines, especially for SCIG and DFIG based. Employment of shunt compensation devices, SVC and STATCOM, at PCC were considered in [22] and [23] for improvement of FSWTs fault related speed stability. Both papers use as a stability measure critical fault clearing times (CCT) – maximum allowable fault duration times before turbines lose stability. In [22] CCT for base case is equal 0.260s. With 1 p.u. SVC and STATCOM compensation CCTs are 0.329s and 0.350s respectively. [23] also states STATCOM superior performance over SVC, however at the price of 30% higher installation costs. Similarly, satisfactory results were obtained in [24] and [25], where STATCOM were used as a solution for DFIG turbines FRT problems.

Different type of FACTS device was proposed in [47] for FRT of FSWTs – SDBR. Authors claim that 0.05p.u. SDBR is equivalent of 0.4p.u. dynamic reactive power compensation device.

Totally different approach to FRT of FS- and DFIG-WTs was proposed by Gamesa in [33]. Instead of shunt compensation DVR was used. This device, by exchanging active power with the grid, injects series voltage between PCC and wind farm terminals to cover voltage reduction caused by grid fault. In such a way fault is not seen from the wind turbine point of view. Thus, it might continue its operation uninterrupted. FRT concepts for DFIG-WTs are also discussed in [24] and [28].

E. *Power quality*

Another research area is wind power quality improvement with FACTS devices. It is especially attractive in case of FSWT connected to a weak grid, where changing wind speed causes voltage fluctuations at wind farm PCC and flicker. In [30] is shown, that dynamic reactive power compensation device like STATCOM can solve this problem.

Very interesting issue is studied in [31]. Capacitances of low loss cables that are used in wind farms together with main transformers inductance form poorly damped resonant tank, with resonance frequency between 11th and 35th harmonic. By proper controller gain selection it can be ensured that real part of STATCOM complex impedance is negative for all signals in desired frequency spectrum. What means that STATCOM would absorb active power carried by harmonics and re-inject active power at fundamental frequency [31]. Voltage control, can still be normally performed.

V. FACTS FOR WPPS – MARKET AND APPLICATIONS

By the same time that more stringent grid connection requirement appeared, FACTS was already a developed technology for grid support and enhancement, proven through a number of applications. In result, an easy market for the FACTS manufacturers has opened, because they were disposing readymade products capable of addressing many of problems that arose due to the new grid codes. Table 2 lists some of the companies, who are offering their products to the wind turbine owners as a solution for the grid compliance.

TABLE II

MARKET AVAILABLE FACTS FOR GRID CODE COMPLIANCE [50]-[57]

Company	Product name	FACTS type	Unit power range
ABB	SVC	SVC	-
ABB	PCS 6000 STATCOM	STATCOM	6-32MVAr
Areva	SVC	SVC	-
Areva	MaxSine SVC	STATCOM	-
AMSC	D-VAR	STATCOM	1-8MVAr
Converteam	PCS	STATCOM	2-30MVAr
Converteam	ProVar	STATCOM	7.5-42MVAr
Gamesa	WINDFACT	DVR	-
S&C Electric Company	PureWave DSTACOM	STATCOM	1.25MVAr
Siemens	SVC	SVC	-
Siemens	SVC Plus	STATCOM	25,35,50MVAr
w2pS	COVERDIP	DVR	0.66-1.65MW
w2pS	VAR2PS	STATCOM	0.15-0.3MW

In fact there are existing applications of wind farms where FACTS were employed for grid code compliance. Few examples are given below.

In Denmark an SVC was installed for 165MW Nysted offshore wind farm and its planned expansion Rødsand 2 with an expected capacity of 207 MW [48]. WPP reactive power exchange with the grid must not exceed +/- 10 % of the nominal installed active power. Therefore, the Radsted SVC is sized to be able to deliver 80.2 MVAr capacitive and 65 MVAr inductive at 132kV [48].

[34] describes how AMSC reactive power support system was used for 159MW Lake Bonney Wind Farm. To comply with ESCOSA grid code, total compensation needed was 110MVAr capacitive and 16MVAr inductive, where at least half o it must had been dynamically available. AMSC proposed two sets of 3x4MVAr of their D-VAR devices. This gives only ±24MVAr in continuous operation. But considering overloading capability of STATCOMs, ±64MVAr can by dynamically supplied for a short time. The rest of the capacitive compensation was completed by shunt capacitors and WPP own reactive power control giving in total the cost efficient solution.

Real measurement from existing applications, where ABB STATCOMs were used, can be found in [49]. Siemens SVC Plus will be employed in the substation of world's largest offshore wind farm in Thanet [50].

VI. DISCUSSION

Since wind power becomes important player on energy market, TSOs through the grid codes try to ensure that WPP would carry responsibility for secure grid operation. FACTS devices offer attractive features that might not only help wind farms to comply with the connection requirements, but what is the most important enhance the grid stability.

TABLE III

COVERED STUDIES OF FACTS APPLICABILITY TO WPP CHALLENGES

WPP challenge \ FACTS		SVC	STATCOM	STATCOM+ES	DBR	TSCS	SSSC	SSSC+ES	SDBR	TCPAR	UPFC
Voltage stability	SCIG	■	■								
	DFIG	■	■								
	FSC										
Q ctrl. coord. WPP+FACTS	DFIG										
	FSC										
Inertia	SCIG										
	DFIG										
	FSC										
Primary frequency control	SCIG			■							
	DFIG										
	FSC										
P ctrl. coord. WPP+FACTS	SCIG										
	DFIG										
	FSC										
SSR mitigation	SCIG										
	DFIG		■								
	FSC										
Power oscillation damping	SCIG										
	DFIG		■								
	FSC										
FTR	SCIG	■	■					■	■		
	DFIG		■					■	■		
	FSC										
Flicker mitigation	SCIG	■									
	DFIG										
	FSC										
Harmonics	SCIG		■								
	DFIG		■								
	FSC		■								
Short circuit current contrib.	SCIG										
	DFIG										
	FSC										
Generator speed stability	SCIG	■	■						■		
	DFIG	■	■						■		
	FSC										

Legend: SCIG – squirrel cage induction generator,
DFIG – doubly fed induction generator,
FSC – full scale converter between generator and grid

One goal of this paper was to identify problems for large scale wind power integration that could be addressed with FACTS devices. Secondarily, basing on recent publications intention was to identify fields for further research in area of FACTS devices for WPPs. Table 3 compares challenges of WPPs against FACTS solutions proposed in the publications.

There are few reasons for such research profile. First of all thyristor based technology is has slower response times than modern fully controllable semiconductor devices. Therefore, dynamic performance of thyristor based devices might not be satisfactory. Moreover, VSC based devices like STATCOM, SSSC, or UPFC are more attractive, because their operation in not so strongly dependent on the grid conditions, like it is in case of thyristor controlled devices. Series devices yet did not receive too much attention in wind power field. This is because these devices are normally deployed inside of the transmission system, not on generation site. Otherwise their effectiveness might be limited [15]. Therefore, reasonably placed series devices are usually out of generation owner control responsibility area. For this reason, applicability of series devices for wind power plants might be seriously limited. On the other hand shunt devices are normally deployed not only inside the transmission network, but at load and generation busses. Therefore, they can be effectively used within WPP owner jurisdiction area. Finally application costs are important driver. SSSC is so far recognized to be too costly for transmission level applications, with respect to the services offered by this device. As well UPFC has only very few experimental applications due to the costs.

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